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Economic analysis of unconventional liquid fuel sources

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ABSTRACT

In this study, the potential of the alternative liquid fuel sources to enter into the liquid fuel market is analyzed based on the cost structures of these sources. Firstly, the current unconventional sources are classified as syncrude, synthetic fuels and biofuels and some basic information including production methods and current production amounts about these alternative sources is explained. Secondly, the production costs are examined to calculate the market entrance prices and shut-down prices for the technologies used to produce liquid fuels from the unconventional sources. Lastly, the structure of the liquid fuel market and the potential of alternative fuels in the market are discussed. Based on the analysis, it is concluded that the liquid fuel market can be characterized as a competitive market in which three factors play important role on determining the entrance into the market. These factors are (1) the corresponding oil prices for entrance and shut-down prices, (2) total capital cost of the project (the level of sunk cost), and (3) the capital cost per daily barrel of capacity. The evaluation of these factors together shows that biofuels are the most preferable option followed by gas-to-liquids. In terms of market entrance price, syncrude is the most advantageous option, but its high capital cost increases the risk. On the other hand, coal-to-liquids is the most risky one with high market entrance price, large initial capital cost and high margin between entrance and shut-down prices.

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1. Introduction

Liquid fuels like gasoline and diesel have been produced from conventional oil for more than a hundred years. Mankind has also used other natural sources like coal, biomass, and natural gas to get liquid fuels. However, none of these materials has become dominant in the fuel market, except some special cases like the ones in Germany, and South Africa. Germany produced liquid fuels from coal in 1940s as a substitution to the fuels originated from petroleum during the World War 2. In this period, 9 indirect and 18 direct liquefaction plants were constructed to produce 4 million tones of gasoline, 90% of total consumption [1]. After the war, the liquefaction plants were closed down, because lots of cheap oil was available around the world [2]. Regarding South Africa, the reason was the trade boycott held in 1950s because of the apartheid policies. As a response to the trade boycott, she started to use large coal reserves to produce liquid fuels to meet the fuel demand [3]. In 1980s, the share of coal based liquids was 60%, but in the following years this ratio has been decreased. Currently, around 30% of the country's gasoline and diesel needs are produced from indigenous coal [1]. In addition to these two extensive usages, several attempts have been carried out mainly in the developed countries, but only few of them have reached the commercial phase. Several technologies have been developed, but the final products have never succeeded to be competitive in terms of costs compared to oil based liquid fuels. These attempts especially were abundant in the high-oil-price periods, but the decline of oil prices always prevented the extensive production of unconventional based liquid fuels.

The interest to unconventional sources has been revived recently thanks to the increase in oil price which has leaded some countries to produce liquid fuels from alternative sources. In addition, many other countries are taking several projects into their agendas, especially the ones having competitive advantages in terms of source. Taking into account the current and forecasted production amount of unconventional based liquid fuels, it is expected that the market share will increase from 3% to 10–18% by 2035 (Fig. 1) [4] based on the level of crude oil price. If oil prices keep increasing, much more liquid fuel would be produced from unconventional sources and the market share will rise to 18% by 2035. However, if price decreases, the market share of unconventional sources reaches only to 10% by 2035 from 3% in 2007. This expectation shows that there are also some other reasons other than oil price that facilitate the entrance of alternative sources into the market. Among these reasons security of supply, diversification of supply, and sustainable development concerns can be mentioned.

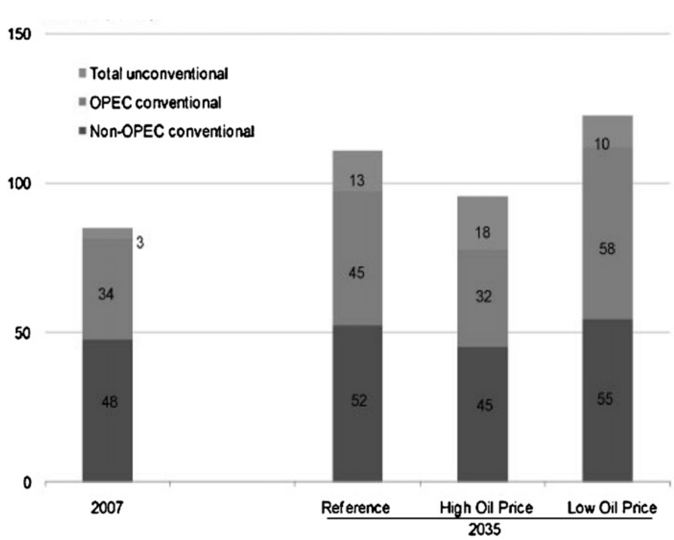

Fig. 1. Unconventional liquid fuel supply in three cases in 2030 (millions bbl/day).

In this paper, the structure of the liquid fuel market is analyzed to understand how and under which circumstances these unconventional sources increase their shares in the market. In the second section, some basic information including technology, reserves, current production, and some applications about these sources is given. Then, in the third section, costs of liquid fuel production from the unconventional sources are discussed. In the fourth section, first the structure of liquid fuel market is evaluated in terms of the competition and then, the entrance of other sources into the market is analyzed by focusing on the entrance prices and shut-down prices.

2. Unconventional liquid fuel sources

The term "unconventional liquids" applies to three different product types: syncrude, derived from the bitumen in oil sands, or from extra-heavy oil, or from oil shales; synthetic fuels, created from coal, or natural gas, or biomass feedstock; and renewable fuels – primarily, ethanol and biodiesel – produced from a variety of renewable feedstocks [5]. Generally, these resources are economically competitive only when oil prices reach relatively high levels. In this section, we will give some basic information about these unconventional sources.

2.1. Syncrude

Syncrude is produced from low quality or immature oil in the forms of oil sands, extra-heavy oil sands and shale oil. These sources are discussed in this section.

2.1.1. Oil sands (bitumen)

Bitumen has some negative properties from crude oil: (1) it has low API gravity that is less than 10; (2) bitumen is composed of carbon-rich, hydrogen poor long-chain molecules; (3) its viscosity is very high compared to crude oil; (4) it generally contains lots of heavy metals and sulfur. Therefore, in the past, the explored bitumen reservoirs had been abandoned undeveloped. Nevertheless, the difficulty of finding new big crude oil reservoir, the increase in oil price, and the development of technology have fostered the production of liquid fuels from oil sands.

Currently, two methods are used to get bitumen from oil sands: open-pit mining and in situ method. If the layer over the oil sand reservoir is thin, open-pit mining becomes less costly option. It is extracted with the physical separation. Then, it is coked, distillated, catalytically converted, and hydro treated to produce syncrude with 86% efficiency on average. Unlike open-pit mining method, in situ process is preferred for reservoirs that are deeper than 225 feet [5]. In in situ process two wells are drilled one of which is used to inject steam or gas to heat and lower the viscosity of bitumen and the other is used to gather the bitumen. Once bitumen is extracted, the remaining process is the same.

The explored oil sand sources are not dispersed thoroughly around the world. Canada solely has 81% of all explored oil sands with 2.5 trillion barrels of bitumen [6]. However, only 321 billion barrels of this resource can be processed under the current economic and technological conditions [7]. If crude oil price remains high, this amount, most probably, will increase in the following years.

2.1.2. Extra-heavy oil

Extra-heavy oil is, in fact, a kind of crude oil whose API gravity is less than 10 and viscosity is higher than regular. As a result it flows slowly in reservoir compared to conventional crude oil. To extract extra heavy oil, steam or gas injected to well, in order to decrease its viscosity.

Contrary to oil bitumen, extra-heavy oil deposits are located in many countries. However, the biggest reservoir, which belongs to Venezuela, has the majority of the extra-heavy oil resource known by now. Petroleos de Venezuela SA, a Venezuelan oil company, estimates the magnitude of the reservoir as 1.36 trillion barrels of extra-heavy oil and the recoverable amount is 270 billion barrels under the current economical and technological structure [5].

2.1.3. Shale oil

Shale oil has become a very popular unconventional liquid fuel source in the last decade because it has a potential to be a real alternative to crude oil especially for the USA. Hence, lots of researches have been conducted in the USA to make it possible to produce synthetic crude oil from oil shale. The reservoir source of shale oil is oil shale which is a calcareous mudstone rock known as marlstone. Oil shale contains kerogen that is the previous phase of petroleum in the maturity path. In other words, kerogen is immature oil which will be crude oil under the condition of moderate to high temperature. Instead of waiting kerogen to be converted into crude oil naturally, the process is done preternaturally by heating oil shale to produce shale oil.

Shale oil is a huge source compared to extra-heavy oil and oil sands with estimated 3 trillion barrels recoverable oil reserves globally [8]. The quarter of this amount belongs to the USA, the biggest liquid fuel consumer of the world [5]. If we take into consideration the daily consumption of the USA about 19–20 million barrels [9], this source solely can meet oil need of the USA more than 100 years.

Like oil sands, oil shale also can be extracted by mining or in situ process. Nonetheless, these deposits are not close to the surface, so only underground mining is possible. In mining, oil shale is mined and transferred to surface facility to produce synthetic crude oil by heating kerogen in a retort to around 520 °C [10]. When heating, hydrogen is injected to enrich hydrocarbons. On the other hand, in in situ process, kerogen is heated by injecting hot liquids or gases into the rock formation. The most important shortcoming of this method is that it takes a long time to start the production of oil.

2.2. Synthetic fuels

Synthetic fuels are coal-to-liquid (CTL), gas-to-liquid (GTL), and biomass-to-liquid (BTL) which are produced within two stages. Firstly, feedstock (coal, gas, or biomass) is used to produce synthetic gases (carbon monoxide and hydrogen). Then, in the second phase these gases are converted into liquid fuels with the Fischer–Tropsch process. The production phases of liquid fuels from coal, natural gas, and biomass are given in Fig. 2 [5].

2.2.1. Coal to liquid (CTL)

Coal is a solid fuel with high carbon content compared to liquids. The current liquid fuels which are consumed for the transportation purposes have hydrogen content around 12–15%, whereas coal contains only 5% typically [1]. Hence, liquefaction process is needed to be able to use it in transportation. CTL technologies simply convert CTL fuels by either removing of carbon or adding hydrogen to increase hydrogen content.

We can classify CTL technologies into three categories: pyrolysis, direct coal liquefaction, and indirect coal liquefaction [11]. Pyrolysis is the oldest technique for obtaining liquids from coal. This technique bases on the heating of coal on the high temperatures around 950 °C in a closed container. Nevertheless, the process produces low amount of liquid fuels which need costly upgrading treatments. The technologies that have been developed solely to produce liquids from coal are DCL and ICL. DCL technology was invented by Friedrich Bergius in 1913. This technology directly produces liquid fuels from coal with the basic process that dissolves coal at high temperature and pressure and adds hydrogen to increase the hydrogen content [11]. DCL is the most efficient technology among the three current technologies. The efficiency level can exceed 70% by weight of pure coal in favorable circumstances. The youngest, but the most widespread CTL technology is ICL technique. It was invented by German scientists Fischer and Tropsch in 1925 and used in the CTL plants in Germany and the UK before 1950s and in South Africa after then. ICL technology adds one more stage to DCL process. While pyrolysis and DCL technologies produce liquids by cracking large molecules like petroleum refineries, ICL firstly converts coal to synthetic gas, mainly carbon monoxide and hydrogen, and then produces liquids from these gases with the help of catalysts.

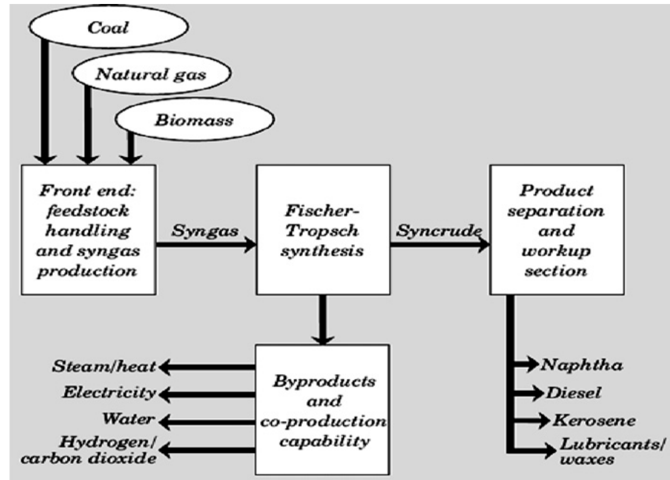

Fig. 2. Synthetic fuel production scheme.

The commercial ICL plants are operating since 1955 in South Africa where the public company Sasol produces several hydrocarbon products in its three plants with a daily capacity of 160,000 bbl [1]. The other commercial production will start in China. Chinese company Shenhua is constructing two ICL plants that will cost $10 billion and start to operate in 2010 [12].

2.2.2. Gas-to-liquid (GTL)

GTL is produced from natural gas by using the Fischer–Tropsch like indirect CTL. This technology converts natural gas into longer-chain hydrocarbons. In the first phase, natural gas is reacted with the air to produce synthetic gases. Then, these gases are directed to the Fischer–Tropsch reactor in the presence of a catalyst to produce liquid hydrocarbons.

Taking into consideration of large capital costs of a GTL plant, the magnitude of reserves should be more than 100 billion cubic meter to supply feedstock to a plant with capacity of 75,000 barrels per day over 25 years [5]. Currently, there are two major commercial GTL projects both in Qatar. One of them is the Oryx GTL plant which is owned by QP 51%, and Sasol-Chevron GTL 49%. This plant produces approximately 30,000 bbl per day of GTL by using natural gas feedstock from the Al Khaleej field in Qatar. The second one is the Pearl GTL project owned by QP 51%, and Shell 49%. This plant is expected to use 1.6 billion cubic meters per day of natural gas. It will produce 140,000 bbl per day of GTL and 120,000 bbl per day of associated condensate and LPG in turn. Currently, the former plant is fully operational and the latter plant is expected to start up at the end of 2010, followed by a ramping up of production in 2011 [13].

2.2.3. Biomass-to-liquid (BTL)

BTL technology produces synthetic gases from waste wood and other non-food plant sources different from the biofuels that are produced from food-related crops. BTL process uses the same tech-

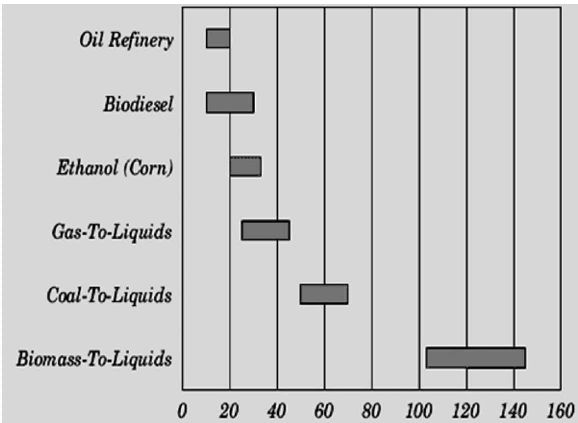

Fig. 3. Capital cost of alternative liquids (thousand 2004 dollars per daily barrel of capacity).

nology (the Fischer–Tropsch process) with CTL and GTL to convert the synthetic gases into hydrocarbons. The most important difference from other synthetic gas sources is that BTL is produced by using renewable sources including wood waste, straw, grain waste, crop waste, garbage, and sewage/sludge [5].

To produce 1 ton of BTL, 5 tons of biomass feedstock is needed. One hectare of land yields 4 tons of BTL and a BTL plant would require the biomass of around 5000 hectare to continue sustained operation [5]. Currently, there is not any commercial BTL production, but there is a project in Europe under construction [14].

2.3. Biofuels

Biofuels are ethanol and biodiesel that are produced from food crops and generally used by being blended with conventional fuels.

2.3.1. Ethanol

It can be produced from any feedstock containing natural sugars such as sugar beets, sugar cane, and corn by fermenting sugars with yeast enzymes. There are three phases in ethanol production. (1) Sugar is extracted from crop by crushing or soaking. (2) Sugar is fermented by using yeasts. (3) The output is distilled to get ethanol.

In 2008, the world ethanol production was around 550 million barrels more than 85% of which was produced by the USA and Brazil [15].

2.3.2. Biodiesel

It is produced from a variety of vegetable oils including soybean, palm, rapeseed and sunflower oil. The technology is mature, proven and simple: The feedstock is derived into an esterification process which removes glycerine. Thus, vegetable oil performs like traditional diesel [5].

Biodiesel production amount is lower compared to ethanol. In 2008, total world biodiesel production was around 80 million barrels only [16]. The most important factor is the high price of feedstock.

3. Cost of unconventional sources

Unconventional sources have different cost structures and consequently different market entrance prices. There are three important cost components for these unconventional liquid fuels: capital cost, feedstock cost, and operation cost. Except biofuels, all of them need huge amount of capital cost at the initial phase compared to oil refinery (Fig. 3) [17], which increases the risk and prevents investor to construct plant to produce liquid fuels from an unconventional source. The crude oil price continuously fluctuates and if it decreases to a certain level, an unconventional fuel production investment faces huge amount of loss.

Table 1
Corresponding oil prices for unconventional liquid fuel sources.

Unconventional source	Corresponding oil price for entrance ($/bbl)	Corresponding oil price for shut-down ($/bbl)
Bitumen	38	20
Extra heavy oil	30	11
Shale oil	70–30[a]	
CTL	86	35
GTL[b]	70	55
BTL	205	
Ethanol[c]	40	25
Biodiesel	81	70

[a] In short-run $70, long-run $30.
[b] Natural gas price is assumed $180 per thousand m^3.
[c] Corn based plant.

In this paper, we will not do detail cost analysis for these sources; instead some figures from several studies will be stated to show the cost structures. As the most important part, capital costs differ from study to study based on the different assumptions including discount rate, plant capacity, and carbon capture regulations. For example, when we look at the capital costs of a CTL plant, several studies propose different figures. While Energy Information Administration of the USA states around $60,000 bbl per day [17], Bartis et al. [3] estimate capital costs bbl per day as $100,000–125,000 for a plant of 80,000 bbl capacity. On the other hand, National Energy Technology Laboratory (NETL) [18] states similar costs in the range of 103,000–123,000 under the plant capacity of 50,000 bbl per day. The mentioned cost estimates are relevant for the USA. The structure is different in China. Sun [19] states that the construction cost of a CTL plant in China that started to operate at the end of 2008 is $62,500 bbl per day. The capital cost of CTL plants which are under construction is also estimated to be around $60,000 bbl per day [12].

While capital costs are important to determine the entrance price, operating costs and feedstock costs are also important not only to calculate the entrance price but also to determine the shutdown-price. Operation costs are generally easier to estimate, but feedstock costs are hard to determine because the prices of these sources are also determined in the market and fluctuates.

To analyze the costs of these different unconventional sources, two prices are used.

1) Market entrance price: This price determines the level of crude oil price that make possible the relevant unconventional source enter into the market by making normal economic profit. In other words, it is a price that covers operating costs and debt, and provides the expected rate of return to its equity investors.
2) Shut-down price: It is the price at which a firm operating in the market stops to produce if the price decreases below this level.

The data about corresponding crude oil prices for market entrance prices and shut-down prices are given in Table 1 which is constructed based on the data from several sources [5,18,20–22].

4. Market analysis

In this section, the structure of liquid fuel market, market entrance and shut-down prices of unconventional liquid fuel sources are analyzed. Firstly, it is discussed whether liquid fuel market is a competitive market by evaluating the market in terms of the characteristics of a competitive market. Then, the market entrance and shut-down prices of different sources are compared to find out

the advantageous sources among them. In this analysis, the level of sunk cost and capital cost per daily barrel of capacity are also considered.

4.1. The structure of the market

In economic theory, a competitive market should have some characteristics, the main ones of which are numerous buyers and sellers, homogenous good, perfect information, profit maximization, and no barrier for entry and exit.

The first and the most important property of a competitive market is the existence of numerous players in the market. It is obvious that there are numerous buyers in the market, but from the producers' standpoint, it is controversial. In fact, there are numerous producers, but some producers act in cooperation under OPEC who supplies nearly the half of total oil production in the world. It is usually claimed that the existence of OPEC causes a deviation from the competitive market structure. However, many studies showed that this claim fails in reality [23] because most of the time OPEC has not had a capability to determine the price in the market. As a result, we can assume that the first condition is satisfied.

In addition to the existence of numerous players, the homogenous product is another factor to consider the fuel market as a competitive market. There are strict standards for each product and no one can introduce a product violating the standards, so this condition is also satisfied.

Thirdly, liquid fuel market also meets the perfect information criteria of the competitive market theory. In other words, in the market, sellers and buyers can easily and quickly learn the prices of different suppliers.

The profit maximization motive is also dominant in the market though sometimes producers can sacrifice short term profit for higher profit in the long term, but it is very rare and generally regional.

However, the liquid fuel market fails in the fulfillment of the last property, no barrier for entry and exit. The entrance into the market needs large capital investment which also limits the exit out of the market. This is an obstacle for competition, but it is only relevant in the short term.

As a result, we can say the assumptions of perfect competition mostly hold in the liquid fuel market and we can consider it as a competitive market.

4.2. Market entrance and shut-down price analysis

In liquid fuel market, there are numerous firms which are classified into several types with different cost structures. Among these types, the costs of the producers who derive liquid fuels from conventional oil are the lowest, though these producers also have different cost structures. Therefore, firstly these firms enter into the market and try to meet the demand. If the demand increases or total production of these firms decreases prices start to go up. If price reaches to the entrance price level of another type of firms producing fuels from an unconventional source, these firms also enter into the market. This process is repeated according to the cost of each source. In this analysis we take into account the corresponding crude oil prices, because the price of crude oil is the most important factor for all unconventional alternative sources. In general, if oil price continues to fluctuate above $50, alternative sources will enter into the market in the long-run and the increase in demand for liquid fuel may be satisfied by these unconventional sources.

For the entrance price analysis, different studies state different prices based on different assumptions about the cost factors including internal rate of return, conversion rate, efficiency rate, feedstock price, and carbon regulations. We analyzed several studies and tried to pick the most sensible figures to construct Table 1 which contains market entrance and shut down prices for the unconventional sources. Regarding the corresponding crude oil price, we can say that syncrude sources are the most competitive among the unconventional sources. If the expectation for crude oil price is over $30 per barrel in the long term, these sources will be the first to enter into the market.

Besides the market entrance price, the magnitude of the initial total capital cost of the project (sunk cost) and the capital cost per daily barrel of capacity is also crucial for entrance. These factors affect the risk level of the investment. This is the reason why biodiesel and ethanol more easily enter into the market compared to syncrude. Actually, when we consider these factors, biofuels are the most advantageous with low amount of sunk cost and low capital cost per daily barrel of capacity despite high entrance price. Among three categories of unconventional sources, synthetic gas sources seem the most disadvantageous with high entrance cost, and high capital costs.

In addition to the market entrance price, the shut-down price that shows the level of market price in which a plant stops to produce is also an important factor for the market analysis of alternative liquid fuel sources. Generally, it is preferable for a source to have low margin between market entrance price and shut down price because this will increase the flexibility and decrease the level of risk. Thus, it will be easier to enter into the market when the price goes up at or above the market entrance price and to exit out of the market when the price goes down below the shut down price with low loss. When we look at the data in Table 1, biodiesel is the most advantageous source with relatively low margin of $11 and it is followed by GTL and ethanol with a margin of $15. On the other hand, CTL has the largest margin around $50, so it is very risky for investors. Therefore, CTL project should be carefully evaluated and only carried out if there is a very strong expectation for market price to be higher than entrance price of GTL for a long time.

5. Conclusion

There are several unconventional sources which can be classified into three different product groups: syncrude from the bitumen in oil sands, or from extra-heavy oil, or from oil shale; synthetic fuels from coal, or natural gas, or biomass feedstock; and renewable fuels – primarily, ethanol and biodiesel – from a variety of renewable feedstock. The unconventional liquid fuels are alternatives to crude oil, but they have not become widespread in the liquid fuel market because of their high production costs compared to the conventional liquid fuels. All of these sources are economically competitive only when oil prices reach to relatively high levels. Hence, the production amount from unconventional sources started to increase with the rising crude oil price in the last decade. If this trend in crude oil price continues, most probably the market share of the unconventional oil sources will be larger in the future.

In this study, the potential of these sources as alternatives to conventional oil examined by focusing on the structure of the liquid fuel market, capital costs, market entrance prices, and shut-down prices. The main results of analysis can be listed as:

- Biofuels are more advantageous when we consider market entrance price, shut-down price, and capital cost structure together.
- GTL is another attractive option with low margin between market entrance price and shut down price, but the need for large initial investment decreases the level of attractiveness of GTL.
- Syncrude sources are the most competitive among the unconventional sources in terms of the corresponding oil price criteria. However, the need of initial high capital investment and high level

of capital cost per daily barrel of capacity makes these sources unattractive.

- The worst option is CTL which has high market entrance price, high initial capital cost and low shut-down price. It is very risky and should not be preferred if market price is not stable above the market entrance price.

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